

# **MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING**

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## **AN EXPERIMENTAL INVESTIGATION OF FLAPPING WING AERODYNAMICS IN MICRO AIR VEHICLES**

**Christopher J. Bradshaw-Ensign, United States Navy  
B.S., Georgia Institute of Technology, 2002**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisor: Kevin D. Jones, Department of Aeronautics and Astronautics**

**Second Reader: Max F. Platzer, Department of Aeronautics and Astronautics**

Flapping-wing propulsion was studied experimentally through Laser Doppler Velocimetry. Measurements were both time-averaged and unsteady, and were conducted on a Micro-Air Vehicle (MAV) model developed at NPS by Professors Max Platzer and Kevin Jones. The objective of this work was to further understanding of the aerodynamics of flapping-wing propulsion. Specifically, this study examined separation control on the leading fixed wing due to entrainment by the trailing flapping wings. Further, a study of wake topology examined differences between the optimal and off-optimal cases. Experimental studies took place in the NPS 5' x 5' low speed wind tunnel. The model was supported on a test stand and LDV measurements of the flow field were taken. Studies were made at varying freestream velocities, angles of attack, and flapping frequencies. The test stand was instrumented with force balances to show forces in both the streamwise and vertical directions.

**KEYWORDS:** Flapping-Wing, Micro-Air Vehicle, Low Reynolds Number, Laser Doppler Velocimetry

## **STUDY OF HYDROGEN AS AN AIRCRAFT FUEL**

**John S. Ciaravino-Ensign, United States Navy  
B.S., United States Naval Academy, 2002**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisors: Oscar Biblarz, Department of Aeronautics and Astronautics**

**Garth V. Hobson, Department of Aeronautics and Astronautics**

The conversion to hydrogen as a naval aviation fuel would allow for independence on fuel cost and supply, as hydrogen is globally accessible. The biggest obstacle to using hydrogen is its very low density, a property that even combined with hydrogen's high heat of combustion still results in very large fuel tanks. Liquid hydrogen (LH<sub>2</sub>) with its higher density would still require a larger volume than kerosene for the aircraft to achieve the same mission. Another problem with using LH<sub>2</sub> is its cryogenic nature, a property that requires complicated fuel tanks and more careful fueling. A design study has been conducted for this report to determine the feasibility of using LH<sub>2</sub>. A Lockheed-Martin P-3 Orion configuration was modified to accommodate LH<sub>2</sub> as its fuel, its mission parameters kept unchanged. It is concluded from this design study that using LH<sub>2</sub> would significantly limit the amount of usable cabin space, as the fuel tank takes up 65% of the aircraft's internal volume. Despite the large LH<sub>2</sub> tank weight of about 14,865lb, due to the low fuel weight the aircraft's takeoff gross weight is only 113,646lb, about 80% of the current petroleum-fueled P-3. The total cost of LH<sub>2</sub> as fuel is currently undetermined.

**KEYWORDS:** Hydrogen Aircraft, Alternative Fuels

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# AERONAUTICAL ENGINEERING

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## **DESIGN AND COLD-FLOW EVALUATION OF A MINIATURE MACH 4 RAMJET**

**Kevin M. Ferguson-Ensign, United States Navy**

**B.S., Massachusetts Institute of Technology, 2002**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisor: Garth V. Hobson, Department of Aeronautics and Astronautics**

**Second Reader: Raymond P. Shreeve, Department of Aeronautics and Astronautics**

Methods used for designing the ramjet included conic shock tables: isentropic flow tables and the GASTURB code were used for aerothermodynamic performance prediction. The flow field through the proposed geometry was computed using the OVERFLOW code, and small modifications were made. Geometry and solid models were created and built using SolidWorks 3D solid modeling software. A prototype ramjet was manufactured with wind tunnel mounting struts capable of measuring axial force on the model. Shadowgraph photography was used in the Mach 4 supersonic wind tunnel at the Naval Postgraduate School's Turbopropulsion Laboratory to verify predicted shock placement, and surface flow visualization was obtained of the airflow from fuel injection ports on the inlet cone of the model. All indications are that the cold-flow tests were successful.

**KEYWORDS:** Ramjet, GASTURB, OVERFLOW, SolidWorks, Shadowgraph, Computational Fluid Dynamics, Stagnation Pressure Ratio

## **UPGRADE OF A LABVIEW® BASED DATA ACQUISITION SYSTEM FOR WIND TUNNEL TESTS OF A 1/10 SCALE OH-6A HELICOPTER FUSELAGE**

**Philipp A. Lines-Ensign, United States Navy**

**B.S., Old Dominion University, 2002**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisor: E. Roberts Wood, Department of Aeronautics and Astronautics**

**Second Reader: Richard M. Howard, Department of Aeronautics and Astronautics**

For over half a century, the NPS Aerolab® Low Speed Wind Tunnel located in Halligan Hall of the Naval Postgraduate School has provided students and faculty with meaningful aerodynamic data for research and problem analysis. New data acquisition hardware was installed three years ago but never fully verified, and contained no integrated software program to collect data from the strain-gauge balance pedestal. Existing national instruments based hardware for the NPS Low-Speed Wind Tunnel was reconfigured to obtain data from the strain-gauge pedestal. Additionally, a data acquisition software program was written in LabVIEW® to accommodate the hardware. The Virtual Instruments (VI) program collects and plots accurate data from all four strain gauges in real-time, producing non-dimensional force and moment coefficients. A research study on the performance of an OH-6A helicopter fuselage was conducted. NPS Aerolab® wind tunnel tests consisted of drag, lift, and pitching moment measurements of the OH-6A along yaw and angle-of-attack sweeps. The results of the NPS wind tunnel data were compared against testing conducted on a full-scale OH-6A helicopter in NASA Ames' 40 ft. x 80 ft. wind tunnel, along with the U.S. Army's Light Observation Helicopter (LOH) wind tunnel tests. Results of current testing substantiate the LabVIEW® code.

**KEYWORDS:** National Instruments Hardware, LabVIEW®, VI, Data Acquisition, Strain Gauge Balance, Wind Tunnel, Hughes OH-6A helicopter, Lift, Drag, Aeromoments

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# AERONAUTICAL ENGINEERING

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## **AN EXPERIMENTAL INVESTIGATION OF THE GEOMETRIC CHARACTERISTICS OF FLAPPING WING PROPULSION FOR A MICRO AIR VEHICLE**

**Jason N. Papadopoulos-Ensign, United States Naval Reserve  
B.S., University of Texas, 2002**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisors: Kevin D. Jones, Department of Aeronautics and Astronautics  
Max F. Platzer, Department of Aeronautics and Astronautics**

The geometric characteristics of flapping-wing propulsion are studied experimentally through the use of a force balance and a Micro Air Vehicle (MAV) system. The system used is built to duplicate the propulsion system currently on the flying model of the Naval Postgraduate School (NPS) MAV model. Experiments are carried out in a low speed wind tunnel to determine the effects of mean separation and plunge amplitude on the flapping wing propulsion system. Additionally, the effects of flapping-wing shape, flapping frequency, and MAV angle of attack (AOA) are also investigated. Some flow visualization is also performed. The intent is to optimize the system so that payload and controllability improvements can be made to the NPS MAV.

**KEYWORDS:** Micro Air Vehicle, Flapping-wing Propulsion, Force Balance, Flow Visualization

## **UNSTEADY PRESSURE MEASUREMENTS ON THE CASE WALL OF A TRANSONIC COMPRESSOR**

**Matt W. Rodgers-Ensign, United States Navy  
B.S., Georgia Institute of Technology, 2002**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisor: Raymond P. Shreeve, Department of Aeronautics and Astronautics  
Second Reader: Garth V. Hobson, Department of Aeronautics and Astronautics**

The method of taking unsteady pressure measurements on a research transonic compressor rig was lost during the transition from the traditionally designed Vavra stage to the Sanger stage. The Sanger stage was designed using computational fluid dynamics (CFD) techniques. It required a new case wall in which the unsteady pressure sensors, due to outdated software and data acquisition system, were not initially installed. In the present study, unsteady pressure measurements were reestablished, with the installation of sensors and development of a new data acquisition and data reduction system. Data were taken at 60%, 70%, and 80% design speed. Data at 60% and 70% were compared to computational predictions and reasonable agreement was obtained.

**KEYWORDS:** Compressor, Transonic, Unsteady Pressure, CFD, Turbomachinery

## **REAL-TIME WIND ESTIMATION AND DISPLAY FOR CHEM/BIO ATTACK RESPONSE USING UAV DATA**

**Cristián Sir-Lieutenant Commander, Chilean Navy  
B.Eng., Educational Headquarters, 1992**

**Master of Science in Aeronautical Engineering-June 2003**

**Advisors: Isaac Kaminer, Department of Aeronautics and Astronautics  
Vladimir Dobrokhodov, National Research Council Research Associate**

The defense response to a Chemical and Biological attack would be importantly based on predicting the dispersion of a toxic cloud. Considering that an Unmanned Air Vehicle would provide the capability for embedding and positioning inertial and air data sensors geographically as required, real-time wind estimation can be performed for every actual position of the flying device in order to predict the plume moving direction. The efforts in this thesis concentrate on the demonstration and validation of procedures for obtaining Wind Estimation close to real-time and its instantaneous monitoring. The work presented is based on a particular UAV platform available at the NPS Aeronautics Department and it aims to establish a general methodology, which may be used on other flying devices with similar available sensors. An

accurate estimation of real wind for a particular combat scenario will enable operational units to have a near real-time decision aid. This final result could be integrated into a Command and Control net, to assist in a focused way the response to a Chemical and Biological attack and to map the source or the region to be affected.

**KEYWORDS:** Unmanned Air Vehicle, UAV, Wind Estimation, Real-time Workshop, xPC Target, SIMULINK, Inertial Measurement Unit, IMU, Coordinate Systems